Performance efficiency and resource allocation strategy for fire department with the stochastic consideration

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Abstract: This research adopted the stochastic Data Envelopment Analysis (DEA) to analyse future performance efficiency through a two-staged problem solving procedure design. In Stage 1, the random production value is applied and then the future performance efficiency of firefighting branches of Tainan County is discussed using DEA. In Stage 2, efficiency improvement and resource allocation are conducted by through a future production trend analysis, and the future optimised scale of firefighting human resources allocation is determined by using the Group-Number Efficiency Scale Approach (GESA). In addition, based on the future trend evaluation, this study can provide suitable response strategies for firefighting human resources allocation for decision makers. Moreover, this study provides a referenced constructive and quantitative approach for solving the current problem of 'how to plan the future resources for optimisation'.

Keywords: data envelopment analysis; DEA; omit resource approach; ORA; multi-stage resource allocation approach; MSRAA; three-point estimate; group-number efficiency scale approach; GESA; fire department.

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1 Introduction

Fire prevention, disaster rescue, emergent medical service and other issues relating to the lives of people are the three major missions of fire department and its branches. People expect that the fire department can adopt the proper countermeasures for disaster prevention and they also hope that fire branches can dispatch rescue teams to efficiently execute their missions – disaster prevention and rescue. However, firefighting is characterised with prevention of future disaster while the current fire branches' performance efficiency evaluation is commonly conducted on the basis of data of the past. Although, its analysis results will provide certain opinions, they are not sufficient for firefighting management in considering future strategies. Especially, thanks to the rapid economic development of Taiwan in recent 30 years, firefighting tend to be heavy in a scenario of heavily exploited land, densely distributed population and types of hazardous factories. Firefighting personnel are prone to professional exhaustion due to long working hours and high danger, leading to undermined performance efficiency. Therefore, economically speaking, to set up an optimised and reasonable firefighting human resource allocation model is to find out a critical point of the relationship between the firefighting capability and disaster rescue and relief. It can avoid investing too much human resources and facilities, thus causing the waste of social cost, or avoid failure of meeting the basic security assurance of people due to lack of human resources and facilities. In the face of ever increasing disaster prevention and rescue cases as well as limited governmental funds, what is the relative efficiency of fire branches in Tainan County as a whole considering the general production of them? Namely, how to achieve the reasonable allocation of the firefighting resources in the coming year? Therefore, it is an important topic to select a proper, fair and reasonable approach to evaluate the future performance efficiency of each fire branch and set reasonable goals as well as make resource adjustment for inefficient branches.

In 1978, Hatry refer to the performance includes three parts as the efficiency, effectiveness and productivity. Richman and Farmer (1975) distinguished the organisational goal into two categories as the efficiency and effectiveness. The ratio between input and output defines as the efficiency (Farrell, 1957), and the production level of the expected goal in a system defines as the effectiveness (Szilagyi, 1984; Robbins, 1996). In fact, the efficiency and effectiveness individually represent different performance requirement and they do not need to achieve simultaneously. However, an effective organisation must take care of both well and pursue its maximum effectiveness in the most efficient way (Richman and Farmer, 1975).

The most common used performance evaluations are Ratio Approach, Regression Analysis, Multiple Criteria Analysis, Analytic Hierarchy Process, Balanced Scorecard, Delphi Hierarchy Process, Total Factor Productivity (TFP) and Data Envelopment Analysis (DEA) (Clarke, 1992; Studit, 1995; Griliches and Regev, 1995; Feng and Wang, 2000; Kaplan and Norton, 2001; Agrell and West, 2001). The DEA is the most appropriate method to evaluate the performance of non-profit organisations because of its characteristic in measuring performances through the use of the multi-evaluation indicators. The performance of fire organisation is classified as multiple inputs and outputs, and the functional relationship between input and output items cannot determine in advance. Therefore, this study adopts DEA to evaluate the performance of fire organisations.

The DEA, presented by Charnes, Cooper, and Rhodes (CCR) in 1978, is a performance evaluation method to apply to the public and non-profit organisations (Charnes *et al.*, 1978), but later it is widely used in many profit organisations. DEA is a performance evaluation method shown by the ratio of input/output and has the same meaning of the so-called TFP (Gleason and Barnum, 1982). The research tries to conduct a relative efficiency evaluation on each fire branches under the consideration of the dual goals on disaster prevention and rescue as well as people's lives protection and property safety. Actually, DEA is applicable to the efficiency comparison in comparing the similar Decision-Making Units – DMUs (Charnes *et al.*, 1978; Forsund and Hjalmarsson, 1979). This research adopts DEA because DEA cannot only strengthen the fairness of the performance evaluation among fire organisations, be an excellent reference in promoting allocation efficiencies of the fire organisations (Athanassopoulos, 1998), but also offer a new era all-around thinking to measure the fire organisation performance.

The American 'Municipal Fire Service Workbook' points out that the purpose of evaluating fire prevention and rescue effects, efficiency and the entire organisational performance of the fire organisations is to provide the local fire administrative system a method to evaluate the entire fire mission execution and to help the municipal administrators or chief executives of fire departments to estimate their own fire system (National Science Foundation, 1977). This study aims to assess the performance efficiencies of fire branches by using 37 fire branches of Tainan County Fire Bureau as an example. In current Taiwan's policy, the allocation of fire manpower is based on the population and size of the administrative area (Lan *et al.*, 2007). Also, the current allocation method of fire manpower only simply considers the location and response time of the fire branch to assign the fire resources (Hausner *et al.*, 1974; Chaiken *et al.*, 1979), but the specific characteristics of control area, the disparity of townships, the expenditures of governmental budget subsidiaries and the size of fire branch do not consider, and thus a biased performance assessment is caused. Thus, the study considers the aspects of control area, loadings of fire duties and government budget in order to establish a reasonable method to assess the future performance of fire branches.

This research adopts a research design of two-stage. First, it uses the approach for estimating future production in the random DEA estimation model which proposed by Sueyoshi (2000) to estimate the future production of each fire branch in Tainan County for efficiency analysis. After completing random DEA performance efficiency analysis of Stage 1, and then the research comes into Stage 2, when the future production tends to become stable, decrease or increase, it used Omit Resource Approach (ORA) to delete redundant resources and Multi-Stage Resource Allocation Approach (MSRAA) to make structurally reasonable resource allocation as proposed by Lan *et al.* (2007). The ORA strategy is to obtain suggestions by contributes of items of DEA analysis. Speaking from the firefighting stance of more importance attached to future than present, by predicting the future performance efficiency and using ORA and MSRAA, the management decision maker can adopt different strategies according to predicted future trend. It provides a constructive and quantitative reference for decision makers in solving the ever present problem of 'how to reasonably allocate resources in the future'.

2 Selections of model, input and output items

This study discusses the future stochastic output performance of each fire branches in Tainan but does not assume the production function of these DMUs. Therefore, DEA is adopted as a satisfied performance measuring method. The DEA has two different models, CCR and Banker, Charnes and Cooper (BCC) (Charnes *et al.*, 1978; Banker *et al.*, 1984), and these two models have different options, the input orientation and the output orientation. In order to examine whether each fire bureau decreases the use of input resources as possible to maintain its current output level, this study utilises the input orientation of CCR to perform the performance analysis on each fire organisation. In Golan and Roll (1989) considered that the selection of input and output items is one of the most important steps in conducting DEA. The commonly used methods on how to determine the proper input and output items are used to interview the organisational hierarchy, analyse the organisational and administrative goals, and gather literatures and experiences to select the appropriate input and output items (Kao, 2000).

Based on the above-mentioned process, this paper selects five input items as 'number of on-duty personnel', 'on-duty cost', 'number of fire engines', and 'vehicle maintenance fee' and two output items as 'number of fire cases' and 'number of emergency rescues cases'. The items 1 and 3 of the above input items are the fire protection resources in the fire organisations (Coleman *et al.*, 1979), and the 'on-duty cost' excludes the budgets of other input resources. Table 1 illustrates the definitions of each input/output item and Appendix 1 takes CCR model shows the details data of each DMU in the 2006. In addition, Table 2 lists the correlation coefficients between input and output variables of the DMUs. According to Table 2, there is a positive correlation among each selected input and output variable in the research and this means that the relation among each variable complies with the isotonicity required by DEA, then this research adopts the backward elimination (Kao, 2000) to omit the input and output items with smaller weights until the weight of each input and output items becomes significance. After conducting the backward elimination, the study cannot omit any variable.

Table 1 The definitions of input and output items

No.	*Input/Output*	*Name of item*	*Definitions*
01	input	Number of on-duty personnel	The monthly average on-duty persons of the fire branch during the period of assessment (person)
02	input	On-duty cost	The business expenses and vehicle fuel expenses of the fire branch during the period of assessment (thousand dollars)
03	input	Number of fire engines	The number of various fire engines in the fire branch during the evaluation period (vehicle)
04	input	Vehicle maintenance fee	The maintenance fee of fire vehicles of the fire branch during the period of assessment (thousand dollars)
01	output	Number of fire cases	The number of fire cases occurred within the control area of the fire branch during the period of assessment (case)
02	output	Number of emergency rescues cases	The number of emergency rescue cases of the fire branch during the period of assessment (case)

Table 2 Correlation coefficient between input and output items

Name of item	*Input1*	*Input2*	*Input3*	*Input4*	*Output1*	*Output2*
Input1	1	0.660	0.815	0.721	0.675	0.753
Input2	0.660	1	0.449	0.435	0.392	0.413
Input3	0.815	0.449	1	0.599	0.828	0.890
Input4	0.721	0.435	0.599	1	0.404	0.467

3 Application of DEA prediction model: production estimation

This research starts from the stance of more importance attached to future than present and input estimation into DEA. By using the production approach of DEA prediction model proposed from Sueyoshi (2000) to estimate future production. Decision makers participating in future planning may use three different types of values in production estimation of DMU to determine the related expected value ($\bar{y}$) and valuable (σ^2):

1 *ML* (Most Likely estimate)

2 *OP* (Optimistic estimate)

3 *PE* (Pessimistic estimate).

The *ML* is the most realistic estimate of all DMU estimates. Statistically speaking, it is the average probability distribution of production (peak). *OP* refers to the possible production in case of smooth producing activities. It can be considered as the upper limit estimate of probability distribution. *PE* is the lower limit estimate of probability distribution, namely, the production in case of very unsmooth producing activities (Sueyoshi, 2000).

Therefore, *OP* and *PE* are two extremes of possibility while *ML* is the probability distribution peak. The three-point estimate's probability is distributed in Beta distribution to calculate the average number (μ) and variable (σ^2). Regarding the probability distribution of most numbers, such as Beta distribution, the whole allocation is basically between ($\mu - 3\sigma$) and ($\mu + 3\sigma$). The three-point estimate can be converted into expected values and variables of production. The allocation average value is $\bar{y} = (OP + 4ML + PE)/6$. The *ML* is represented by $(OP + PE)/2$ of the data in this research. Secondly, $\sigma^2 = (OP - PE)/6$. This research uses the approach to estimate expected production values and variables. This approach can cover uncertainties of the future, complying with the characteristics of future uncertainty planning of fire prevention and emergency rescue.

4 Empirical study and analysis

This section is discussed about the production estimation, efficiency analysis and resource strategy. The production estimation is first to be discussed.

4.1 Production estimation

In many real management problems, it is often applicable to determine variables by invested quantity. On the other hand, it is rather difficult to manipulate production. Because production is not determined only by management decision, instead, it is affected by the temporary economic situation, changing population and other outside factors which may make it out of control (Anderson *et al.*, 1982). Therefore, this research considers the input as the determining variable and the production as the random variable in prediction analysis. The two productions of this research are random variables. The problem is how to get three estimates for each production (*ML*, *OP*, *PE*).

Before working out the efficiency by prediction model, for the comparison with the past, CCR model is used to work out the efficiency value. The data used here are the real values of input and production in 2006, and details are in Appendix 1. First, data of fire and emergency relief cases between 2002 and 2005 was used to estimate the random production value of 2006 for comparison with real production of 2006. The results of the analysis of prediction model showed that the real production values of DMUs in 2006 fell within the range of the prediction model ($\mu \pm 3\sigma$). And the real average efficiency value of Tainan County Fire Department in 2006 was 0.7831 with 10 branches of efficiency value at 1. The random production average efficiency value was 0.7301 with 11 branches of efficiency value at 1. The Efficiency Affection Index (EAI) is, $\text{EAI} = \left| \frac{11-10}{11} \times 100\% \right| = 9.09\%$. The rather low EAI value at 9.09% represents that the random production prediction model is reasonably close to the real situation with no conspicuous difference between efficiency values as shown in Appendix 1.

Next, for understanding the random production performance efficiency of 2007 with planning the future fire prevention, this research adopts variables including the number of personnel, cost of services, number of fire vehicles and cost of fire vehicle maintenance of the Tainan County Fire Department in 2006, all of these are controllable. The random production is the estimation of 2007, which is processed on the basis of future estimates rather than past data. As it is impossible to obtain production values related to future directly from the current data, each branch under evaluation is requested to provide three different estimates (*ML*, *OP*, *PE*). The random production of this research is the *ML*, *OP*, *PE* values deduced from the data of the fire and emergency relief cases between 2002 and 2006. If the production estimate of the calculation results is integral, it is considered as the estimate. If not, the number will be unconditionally rounded up. Appendix 2 is the estimates of input in 2006 and production of DMUs in 2007. The average value of the 2 production estimates worked out by these estimates, the standard deviation, and standard distribution Z value as well as details of 37 branches' 2 production estimates of 2007 are listed in Appendix 3. The sample results of 2006 attached in this research is to test whether DEA efficiency under random variables and the traditional DEA efficiency are different. In fact, the general management did not know how to use the future information for analysis when making strategy adjustment in 2006.

4.2 *Efficiency analysis*

Frontier software was applied to investigate 37 fire branches of Tainan Fire Bureau in Taiwan by using the input are considered as deterministic variables of 2006 and the output are considered as stochastic variables of 2007 to perform the efficiency analysis. The efficiency analysis is described below.

The production efficiency derived from the CCR model of DEA includes the technical efficiency and the scale efficiency. The production efficiency, the technical efficiency, the scale efficiency and the return to scale of each fire branch in Tainan County are listed in Appendix 4. For example, the production efficiency of fusing branch is 0.7026, its technical efficiency is 0.7557 and the scale efficiency is 0.9297. It reveals that the production inefficiency of fusing branch is mainly due to its technical factor because its technical efficiency (0.7557) is smaller than the scale efficiency (0.9297). The analysing results of DEA for those 37 fire branches in Tainan County are described as follows: Firstly, the production efficiencies from 7 among 37 branches are equal to 1. Secondly, regarding to the technical efficiency, there are 16 fire branches whose technical efficiencies are equal to 1. Thirdly, the scale efficiencies of 7 fire branches among 37 branches are equal to 1. Fourthly, for analysing the return to scale, there is one fire branch (*i.e.*, Guanmiao fire branch) which has been categorised into the Decreasing Return to Scale (DRS). Those three DRS branches mean that they can try to decrease their scale for efficiency improvement. Seven fire branches are in the category of Constant Return to Scale (CRS); this indicates that these seven branches have already reached the optimal production scale. The 29 fire branches left are in the category of Increasing Return to Scale (IRS) meaning that those 29 IRS branches can try to amplify their scales for efficiency improvement. The detailed information of DRS, CRS and IRS for those 37 fire branches is listed in Appendix 4.

4.3 Resource strategy

Efficiency assessment is a method but not a goal to the administrative control. By the potentially improved targets and improved levels of fire organisations in each county and city, we do not need to input resources to the relative inefficient units, whereas these units need to appropriately reduce resources. According to the empirical analysis, the average efficiency of the entire fire branches is 0.7207 and it means that the total has about 28% of the input resources being ineffective and wastes. The reason of causing production inefficiency is the average technical efficiency, 0.9180 and the average scale efficiency is 0.7767. Therefore, Lan *et al.* (2007) proposed the ORA and hoped to reduce resources according to the DEA report data when the future output trend is steady or decreasing (Lan *et al.*, 2007). When executing reduction, how should the administrators accurately and reasonably reduce which input resource first? Based on the contribution index data analysis of the DEA report, the administrators should start from the resource with a greater contribution index because the output value of each fire branch cannot change arbitrarily. Meanwhile, ORA strategy is to effectively and properly balance the uneven work loading of the relative inefficient units if the administrators can reduce the input resources to these units when the future output trend is steady or decreasing.

On the contrary, when the future production is on the up trend, strategy planning can be standing on MSRAA which proposed by Lan *et al.*, (2007). MSRAA expects to balance the branch workload of the relatively high effective unit with other branches. How does the management dispose the resources reasonably and accurately to branches that the department who really need the resource? In view of this, the MSRAA strategy proposed by Lan *et al.*, (2007) can provide a constructive and quantitative reference model for firefighting resource allocation decision makers in allocating resources (Lan *et al.*, 2007).

Due to the increase of population in Taiwan, the fire-related damage cost, fire prevention related cost and the total systematic cost will be increasing as proposed by Bryan (1979). As a matter of fact, the fire department's production such as rescue cases increases year by year, the local government has to increase firefighting resource input to serve the social public. The current human resources budget of Tainan County fire department is 556 with only 446 in service, being short of 110 firefighters. How does the management increase firefighters year by year within the budget? What is the annual human resource increase? In consideration of increasing resources, more fire branches are expected to become efficient units in the interest of annual firefighting human resources and raising the general efficiency. As the current efficiency is involved with many unconsidered factors, to understand how the decision makers plan to allocate resources to the optimised state, this research proposes Group-Number Efficiency Scale Approach (GESA) as a reference for fire branches resource allocation makers in planning future resources.

As indicated from the 2007 estimate analysis, 81.08% of all the fire branches are inefficient. The reasons for inefficiency of some fire branches are: 56.76% fire branches are technically inefficient, 81.08% fire branches are inefficient in scale. Namely, the rise of the general efficiency of all fire branches shall start from the fire branches allocation. Considering impossible general efficiency of all fire branches, with GESA, this research expects to increase units of relative higher efficiency to allocate governmental resources more reasonably. If increasing input in these units of relatively higher efficiency, it can effectively reduce the job overloading of these branches. How does the management plan the scale of future resources? In view of this, the GESA strategy proposed in this research can serve as reasonable and quantitative reference for resource allocation maker in planning future firefighting human resources. The GESA execution steps are discussed as the following list:

Stage 1

Step 4 The minimum Resource Allocation unit is defined as one firefighter and the original efficiency values of branches listed under evaluation of the DEA analysis report (Frontier software) by order, of which branches of relatively higher efficiency form the preliminary set. The decision-making branches considered as efficient are defined as candidate branches for human resources input.

Stage 2

Step 5 One unit of resource is allocated to branches of relatively higher efficiency in the preliminary set of Stage 1 and the number of branches of efficiency as well as the general performance efficiency value of all the branches under evaluation in current circumstances calculated (with Frontier software). If the number of branches of efficiency and the general performance efficiency value are less than those of the preliminary set, resource allocation is stopped. The optimised solution is the preliminary set of the previous stage (recommended solution), and Stage 5 is entered otherwise Stage 3 is entered.

Step 6 Resources are allocated to various branches of efficiency according to Step 2 and the number of branches of relatively efficiency and the general performance efficiency value of branches under evaluation in current circumstance calculated. If the number of branches of efficiency and the general performance efficiency value are bigger than or equal to those of the preliminary set, all the branches under evaluation are listed by order to be the preliminary set for the next Stage. Its branches of efficiency are the candidates for human resource input for the next stage.

Stage 3

Step 4 Stage 3 defines the recommended solution of Step 3 (preliminary set) as the input unit to find out the optimised general value of fire branches. If the value is less than the previous Stage, input is stopped and the Stage recommended solution obtained. If the value is bigger than the previous Stage, resources are invested according to Step 3 until the optimised value and the maximum general performance efficiency value are found out. If the number of branches of efficiency decreases with increasing general performance efficiency value, input is stopped as it indicates that the increase of resource input reduces the number of branches of efficiency. Then, the optimised solution is the recommended solution of the previous stage.

Step 5 All the allocation records are integrated to form the recommended solution, from which the total resources for next year can be learnt. This solution is also the GESA optimised solution.

At present, although, firefighting in Taiwan is the local government's obligation, the firefighting services and standard procedures are the same across Taiwan. Firefighting resources are allocated subjectively by local governments depending on different financial status. However, newly hired firefighting human resources are allocated across Taiwan by the central authority. There is a lack of 110 firefighters according to its budget in Tainan County. Limited by the nationwide allocation of the central authority, the lack can never be made up once for all. Therefore, Tainan County Fire Department needs to hire new firefighters in the following years. Taking firefighting human resource make up as an example, how many firefighting personnel shall be recruited into Tainan County Fire Department to achieve the general optimised efficiency and best human resources allocation? By DEA analysis report and GESA execution steps, the calculation process is discussed in detail as follows: First, the original efficiency values of branches under evaluation is listed in the DEA estimate analysis report in 2007 (Frontier software) to form the preliminary branches efficiency set and the minimum allocation unit of human resource defined as one firefighter. These decision-making units of efficiency are the candidate branches of human resources input at the present stage with the rest fire branches kept unchanged. There are seven fire branches of efficiency from the DEA estimate analysis at Stage 1. The original general efficiency value is 2666.52. The seven fire branches of efficiency are defined as the preliminary set.

At Stage 2, the seven fire branches of efficiency are defined as the human resource input candidate units and one firefighter is added for each branch with the rest fire branches kept unchanged. After calculation, the number of fire branches of efficiency increases by three to make the total branches of efficiency as ten and the general efficiency value is 2733.61. After the increase of seven firefighting personnel at Stage 2, the number of total branches of efficiency and the general efficiency value increase compared with those of Stage 1. Next, the 10 fire branches of efficiency and 27 fire branches of inefficiency at Stage 2 are listed to be fined as the preliminary set for the next stage.

At Stage 3, the recommended solution of Stage 2 is defined as the candidate unit of human resource input and one firefighter is added to each branch with the rest fire branches kept unchanged. After calculation, the number of fire branches of efficiency increases by 1 to make the total branches of efficiency as 11 and the general efficiency value is 2778.78. After the increase of ten firefighting personnel at Stage 3, the number of total branches of efficiency and the general efficiency value increase compared with those of Stage 2. Next, the 11 fire branches of efficiency and 26 fire branches of inefficiency at Stage 3 are listed to be fined as the preliminary set for the next stage.

At Stage 4, the 11 fire branches of efficiency of Stage 3 is defined as the candidate unit of human resource input and one firefighter is added to each branch with the rest fire branches kept unchanged. After calculation, the number of fire branches of efficiency remains to make the total branches of efficiency as 11 and the general efficiency value is 2822.07. Next, the 11 fire branches of efficiency and 26 fire branches of inefficiency at Stage 4 are listed to be fined as the preliminary set for the next stage.

At Stage 5, the recommended solution of Stage 4 is defined as the candidate unit of human resource input and one firefighter is added to each branch with the rest fire branches kept unchanged. After calculation, the number of fire branches of efficiency increases by 3 to make the total branches of efficiency as 14 and the general efficiency value is 2880.45. After the increase of 11 firefighting personnel at Stage 5, the number of total branches of efficiency and the general efficiency value increase compared with those of Stage 4. Next, the 14 fire branches of efficiency and 23 fire branches of inefficiency at Stage 5 are listed to be fined as the preliminary set for the next stage.

At Stage 6, the 14 fire branches of efficiency of Stage 5 is defined as the candidate unit of human resource input and one firefighter is added to each branch with the rest fire branches kept unchanged. After calculation, the number of fire branches of efficiency decreases to 11 and the general efficiency value increases to 2915.4. The decrease of branches of efficiency by three indicates that increase of resources has reduced the number of branches of efficiency. Thus, the increase of firefighting personnel shall be stopped to save resources. After learning that Stage 5 has achieved the optimised allocation of number of branches of efficiency. The number of branches of efficiency and the general efficiency values are as shown in Appendix 5 after completing allocation stages with GESA.

This approach can timely solve the heavy firefighting workload for decision-making units of less production to invest relatively less human power for mission while units of relatively more production shall invest relatively more human power. According to the above calculations, it is learnt that Tainan County Fire Department shall recruit 39 firefighters to gradually achieve the allocation budgeted number. And the obtained budgeted human resource scale can be used to estimate the next year human resources requirements. Hence, this research can make adjustment according to the efficiency values obtained and plan human resource recruitment, budget making and fire vehicle purchase for the next three years according to allocation scale. This approach can serve as the objective reference to raising firefighting units' efficiency by helping fire branches in human resources planning.

5 Conclusions and suggestions

Performance efficiency evaluation is an important management issue which is more and more valuable for administrative organisations and enterprises. A better performance efficiency always becomes the guarantee of management. In order to achieve the administrative, the morale, the efficiency and the enterprise objectives, the efficiency measure is one of the most important methods to be conducted. The performance evaluation not only builds up the supports of organisation aims from the organisation members but also reveals the flaws of management. Most of the current DEA performance efficiency evaluation researches is conducted the analyses by applying the past data, but it is impossible to understand that how to use strategic planning for solving other decision-making problems through the random production in the future. Therefore, standing on the stance of firefighting that the stance in the future is more important than the past. This research adopted the estimate methods of stochastic DEA methods to analyse the future performance efficiency. In fact, resource allocation can affect these aspects such as the organisational efficiency and productivity. The unreasonable allocation of resources can have a major impact on the organisational operation. Fortunately, the DEA analysis in the future and resource strategy proposed in this research, it is easy to understand the difficulty and complexity for the decision-making management in the future.

With respect the resource strategy, this research discusses how the management decision maker makes his decisions concerning about the resource allocation in case of changing future production trend. ORA and MSRAA provide decision makers a referenced resource adjustment. If the production is estimated to decrease or remain the same in the future, the input in branches of relatively less efficiency shall be simplified. ORA strategy provides management decision maker a way of determining by input contributions. On the contrary, in case of estimated increase trend, how does the management decision maker reasonably and accurately allocate the resources to branches that really need those in case of inevitable resource increase? MSRAA is applied for reasonable resource allocation. However, this research believes that it is a rather superficial way to eliminate resources. The fundamental way of solving the problem is lied in the resource allocation rules. After learning the present human power shortage, how the decision maker rationally to plan the future resource allocation year by year and consider the optimised scale under the branches of general efficiency? The GESA proposed in this research can provide analysis of number of branches of efficiency and performance efficiency values for decision makers to determine the order of each branch of relative efficiency for reasonable future resource allocation. The above resource allocation strategies can help decision makers find out the fast way to successful solve and serve as a constructive and quantitative approach.

As a matter of fact, the fire branch has the responsibility of public safety, and its scale of firefighting resources need to be seriously considered. Therefore, if the input resources of relative inefficient branches are greatly reduced, the public safety of locality will be affected and hindered. Consequently, the decision maker has to consider the appropriate scale of fire resources for each fire branch while performing ORA strategy. Based on the ever increasing population of Tainan County, the future fire protection duties will accordingly become heavier. Therefore, the proposed GESA strategy in this study will impersonate an important role in the allocation of future fire protection resources. And it can support as an importance reference when implementing fire public safety policies in case of fixed budget of the local government. This paper can also provide fire branches to allocate limited resources to towns with more population and distribute firefighting capability with consideration of local characteristics. It can help the decision maker to develop fire branch distribution, effectively plan and allocate fire branches. It cannot only raise the efficiency for rescue and relief for fire branch but also rationally allocate and effectively make use of social resources by limited firefighting human power and facilities. It can help us to keep social resources while fully guarantee the welfare and safety of people. Hence, the discussion on how to appropriately use the DEA efficiency value to obtain the general efficiency scale if the future resources input to implement reasonable future resource allocation shall be carried out for the benefits of the decision-making units. In summary, this research proposes a constructive and quantitative fire resource allocation method and further establishes and executive prototype of the new era to pursue higher efficiency.

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Appendix 1

The values of input and output items for each DMU

	Deterministic DEA (2006)							Stochastic DEA (2006)		
Fire branch	*Input 1*	*Input 2*	*Input 3*	*Input 4*	*Output 1*	*Output 2*	*Efficiency*	*Output 1*	*Output 2*	*Efficiency*
Sinying fire branch	18	268.575	6	175.795	138	2030	1	214	2134	1
Yanshuei fire branch	7	188.476	3	36.459	66	945	0.9520	100	841	1
Liouying fire branch	7	115.367	3	12.062	51	772	0.8832	92	629	0.9898
Baihe fire branch	8	210.896	4	35.368	65	901	0.8006	115	823	0.8841
Guanling fire branch	5	82.326	2	3.35	8	177	0.3733	7	121	0.2989
Houbi fire branch	7	125.684	3	38.511	52	636	0.7306	75	545	0.7190
Dongshan fire branch	7	97.813	3	41.086	47	507	0.7071	57	434	0.6746
Dongyuan fire branch	7	52.488	2	3.35	15	258	0.6106	22	220	0.6514
Syuejia fire branch	9	152.488	4	81.113	58	707	0.6432	70	623	0.5888
Jiangjyun fire branch	6	79.863	3	24.85	59	455	1	57	366	0.7859
Beimen fire branch	6	139.386	3	17.1	47	345	0.6256	30	223	0.3208
Jialu fire branch	10	195.455	4	57.92	100	1261	0.9762	127	1216	1
Sigang fire branch	7	88.657	4	3.35	68	738	1	83	567	1
Cigu fire branch	8	146.83	3	26.244	81	601	0.9613	81	454	0.6530
Madou fire branch	15	2981.26	5	64.42	108	1423	0.7941	124	1411	0.8789
Siaying fire branch	8	174.987	4	25.55	45	840	0.7238	50	708	0.7329
Lioujia fire branch	9	133.232	3	4.25	52	704	1	83	630	1
Guantian fire branch	8	165.795	4	28.93	80	802	0.8515	101	689	0.7806
Shanhua fire branch	11	176.559	5	282.005	89	1194	0.8810	99	981	0.7475
Anding fire branch	9	165.127	4	66.05	85	761	0.8519	89	620	0.6449
Danei fire branch	7	102.326	3	120.074	37	377	0.5433	28	280	0.3444
Yujing fire branch	6	132.079	3	34.8	35	595	0.6835	38	467	0.6289
Nansi fire branch	7	164.053	2	47.051	20	441	0.5846	22	327	0.4760
Nanhua fire branch	6	109.86	3	5.6	20	268	0.3918	16	136	0.2433
Sinhua fire branch	11	249.891	4	42.771	132	1319	1	207	1213	1
Shansun fire branch	8	132.339	3	34.24	26	346	0.3641	35	242	0.3145
Zuojhen fire branch	6	82.859	3	3.35	21	208	0.3853	13	171	0.3519
Sinshih fire branch	18	276.748	5	157.108	91	1120	0.6494	108	1014	0.5789
Nanke fire branch	14	203.34	4	113.189	17	558	0.3739	19	275	0.1945
Yongkan fire branch	13	257.741	5	31.447	117	1886	1	156	1536	1
Yanhang fire branch	11	160.887	5	10.158	110	1239	1	117	1030	1
Fusing fire branch	24	3208.885	6	268.902	143	1696	0.8125	149	1498	0.7020
Dawan fire branch	10	240.929	5	48.51	70	1383	0.9533	70	1263	1
Gueiren fire branch	12	304.148	5	29.438	157	1456	1	211	1366	1
Rende fire branch	10	232.515	5	70.931	110	1388	1	159	1070	0.9365
Wunsian fire branch	9	211.957	4	50.5	107	1160	1	140	907	0.8893
Guanmiao fire branch	12	284.772	5	101.25	131	1236	0.8672	229	925	1

Appendix 2

Inputs and output estimates

DMUs	Input items (2006)				Output 1			Output 2		
	Input 1	*Input 2*	*Input 3*	*Input 4*	*PE*	*ML*	*OP*	*PE*	*ML*	*OP*
Sinying fire branch	18	268.575	6	175.795	138	189	219	1227	1964	2103
Yanshuei fire branch	7	188.476	3	36.459	52	86	135	745	845	1007
Liouying fire branch	7	115.367	3	12.062	51	91	102	516	681	772
Baihe fire branch	8	210.896	4	35.368	65	104	126	798	830	901
Guanling fire branch	5	82.326	2	3.35	6	7	8	114	143	177
Houbi fire branch	7	125.684	3	38.511	52	70	92	441	591	644
Dongshan fire branch	7	97.813	3	41.086	43	55	90	359	486	521
Dongyuan fire branch	7	52.488	2	3.35	15	18	33	204	242	293
Syuejia fire branch	9	152.488	4	81.113	51	73	83	556	631	749
Jiangjyun fire branch	6	79.863	3	24.85	50	59	70	300	421	503
Beimen fire branch	6	139.386	3	17.1	27	32	58	145	300	345
Jialu fire branch	10	195.455	4	57.92	88	126	132	828	1196	1397
Sigang fire branch	7	88.657	4	3.35	68	79	91	401	624	750
Cigu fire branch	8	146.83	3	26.244	71	81	102	348	507	602
Madou fire branch	15	2981.26	5	64.42	107	109	134	1006	1397	1512
Siaying fire branch	8	174.987	4	25.55	45	48	57	543	748	840
Lioujia fire branch	9	133.232	3	4.25	52	83	97	571	667	760
Guantian fire branch	8	165.795	4	28.93	80	93	110	642	695	802
Shanhua fire branch	11	176.559	5	282.005	86	89	110	797	1017	1194
Anding fire branch	9	165.127	4	66.05	81	85	105	557	618	772
Danei fire branch	7	102.326	3	120.074	21	37	45	253	323	377
Yujing fire branch	6	132.079	3	34.8	30	35	53	394	511	605
Nansi fire branch	7	164.053	2	47.051	16	25	35	276	379	441
Nanhua fire branch	6	109.86	3	5.6	11	20	47	145	268	277
Sinhua fire branch	11	249.891	4	42.771	132	171	238	1049	1183	1319
Shansun fire branch	8	132.339	3	34.24	26	35	43	237	255	376
Zuojhen fire branch	6	82.859	3	3.35	11	16	21	108	201	248
Sinshih fire branch	18	276.748	5	157.108	91	100	117	917	1001	1143
Nanke fire branch	14	203.34	4	113.189	15	20	42	10	467	558
Yongkan fire branch	13	257.741	5	31.447	114	119	177	368	1609	1886
Yanhang fire branch	11	160.887	5	10.158	94	110	137	893	998	1239
Fusing fire branch	24	3208.885	6	268.902	133	148	149	1263	1428	1696
Dawan fire branch	10	240.929	5	48.51	57	70	87	1012	1266	1383
Gueiren fire branch	12	304.148	5	29.438	157	193	217	1140	1402	1456
Rende fire branch	10	232.515	5	70.931	104	123	197	777	1054	1424
Wunsian fire branch	9	211.957	4	50.5	107	125	157	706	925	1160
Guanmiao fire branch	12	284.772	5	101.25	131	188	229	581	963	1236

Appendix 3

Mean and standard deviation of output estimates

	Output 1			Output 2			Output estimates value (2007)		
DMUs	Mean	Standard deviation	Z value	Mean	Standard deviation	Z value	Output 1	Output 2	Efficiency
Sinying fire branch	185.5	13.5	1.95056	1864.33	146	2.53611	212	2235	1
Yanshuei fire branch	88.5	13.83	0.10312	855.33	43.67	0.24453	90	867	0.9434
Liouying fire branch	86.17	8.5	–0.06958	668.67	42.67	–0.23613	86	659	0.9619
Baihe fire branch	101.17	10.17	0.34811	836.5	17.17	0.18573	105	840	0.8363
Guanling fire branch	7	0.33	–1.57565	143.83	10.5	–1.50988	7	128	0.3046
Houbi fire branch	70.67	6.67	–0.29850	574.83	33.83	–0.46494	69	560	0.6940
Dongshan fire branch	58.83	7.83	–0.52742	470.67	27	–0.73492	55	451	0.6689
Dongyuan fire branch	20	3	–1.26239	244.17	14.83	–1.26604	17	226	0.6376
Syuejia fire branch	71	5.33	–0.35071	638.17	32.17	–0.27190	70	630	0.5763
Jiangjyun fire branch	59.33	3.33	–0.53546	414.5	33.83	–0.86525	58	386	0.8302
Beimen fire branch	35.5	5.17	–0.93708	281.67	33.33	–1.19940	31	242	0.3251
Jialu fire branch	120.67	7.33	0.60113	1168.17	94.83	0.95302	126	1259	0.9724
Sigang fire branch	79.17	3.83	–0.10572	607.83	58.17	–0.35666	79	588	1
Cigu fire branch	82.83	5.17	–0.06556	496.33	42.33	–0.63202	83	470	0.6746
Madou fire branch	112.83	4.5	0.65334	1351	84.33	1.34891	116	1465	0.8027
Siaying fire branch	49	2	–0.71217	729.17	49.5	–0.09208	48	725	0.6509
Lioujia fire branch	80.17	7.5	–0.18203	666.5	31.5	–0.25867	79	659	1
Guantian fire branch	93.67	5	0.20352	704	26.67	–0.10972	95	702	0.7499
Shanhua fire branch	92	4	0.21557	1009.83	66.17	0.59192	93	1049	0.7471
Anding fire branch	87.67	4	0.06296	633.5	35.83	–0.24348	88	625	0.6414
Danei fire branch	35.67	4	–1.05355	320.33	20.67	–1.08573	32	298	0.3819
Yujing fire branch	37.17	3.83	–0.92101	507.17	35.17	–0.61193	34	486	0.5818
Nansi fire branch	25.17	3.17	–1.23026	372.17	27.5	–0.96569	22	346	0.4677
Nanhua fire branch	23	6	–1.25034	249	22	–1.29152	16	221	0.3801
Sinhua fire branch	175.67	17.67	1.74574	1183.33	45	1.07257	207	1232	1
Shansun fire branch	34.83	2.83	–1.02945	272.17	23.17	–1.15090	32	246	0.3002
Zuojhen fire branch	16	1.67	–1.39492	193.33	23.33	–1.42283	14	161	0.3194
Sinshih fire branch	101.33	4.33	0.35614	1010.67	37.67	0.64042	103	1035	0.5631
Nanke fire branch	22.83	4.5	–1.24632	406	91.33	–0.92600	18	322	0.2164
Yongkan fire branch	127.83	10.5	1.07905	1448.33	253	1.42682	140	1810	1
Yanhang fire branch	111.83	7.17	0.54892	1020.67	57.67	0.71245	116	1062	1
Fusing fire branch	145.67	2.67	1.17946	1445.17	72.17	1.72766	149	1570	0.7026
Dawan fire branch	70.67	5	–0.29449	1243.17	61.83	1.15146	70	1315	0.9445
Gueiren fire branch	191	10	2.07507	1367.33	52.67	1.38615	212	1441	1
Rende fire branch	132.17	15.5	1.04692	1069.5	107.83	0.81142	149	1157	0.9342
Wunsian fire branch	127.33	8.33	0.86620	927.67	75.67	0.43121	135	961	0.8862
Guanmiao fire branch	185.33	16.33	2.00679	944.83	109.17	0.47530	219	997	0.9698

Appendix 4

The production efficiency, the technical efficiency, the scale efficiency, and the return to scale of each fire branch

No.	*DMUs*	*Production efficiency*	*Technical efficiency*	*Scale efficiency*	*Σλ value*	*Return to scale*	*Reference set item*	*Number by reference*
1	Sinying fire branch	1	1	1	1	CRS	1	16
2	Yanshuei fire branch	0.9434	1	0.9434	0.525519	IRS	30.34	0
3	Liouying fire branch	0.9619	1	0.9619	0.628995	IRS	1.13.25.3	0
4	Baihe fire branch	0.8363	0.9419	0.8879	0.545253	IRS	30.34	0
5	Guanling fire branch	0.3046	1	0.3046	0.158533	IRS	13.17.31	0
6	Houbi fire branch	0.6940	0.9336	0.7434	0.405905	IRS	1.13.25.3	0
7	Dongshan fire branch	0.6689	0.9236	0.7242	0.457061	IRS	1.13.25	0
8	Dongyuan fire branch	0.6376	1	0.6376	0.300928	IRS	13.30	0
9	Syuejia fire branch	0.5763	0.7584	0.7599	0.335628	IRS	1.25.30	0
10	Jiangjyun fire branch	0.8302	1	0.8302	0.622635	IRS	13.25	0
11	Beimen fire branch	0.3251	0.9118	0.3566	0.161824	IRS	25.30.34	0
12	Jialu fire branch	0.9724	1	0.9724	0.739471	IRS	1.25.30	0
13	Sigang fire branch	1	1	1	1	CRS	13	14
14	Cigu fire branch	0.6746	0.9274	0.7274	0.505982	IRS	13.25	0
15	Madou fire branch	0.8027	0.8537	0.9403	0.764376	IRS	1.30	0
16	Siaying fire branch	0.6509	0.8637	0.7536	0.400552	IRS	30	0
17	Lioujia fire branch	1	1	1	1	CRS	17	3
18	Guantian fire branch	0.7499	0.9046	0.8290	0.537623	IRS	1.13.25.3	0
19	Shanhua fire branch	0.7471	0.8568	0.8720	0.497044	IRS	1.30	0
20	Anding fire branch	0.6414	0.7786	0.8238	0.546279	IRS	1.13.25	0
21	Danei fire branch	0.3819	0.8241	0.4634	0.223443	IRS	1.13.25	0
22	Yujing fire branch	0.5818	0.9974	0.5833	0.268508	IRS	30	0
23	Nansi fire branch	0.4677	1	0.4677	0.163737	IRS	1.30	0
24	Nanhua fire branch	0.3801	0.8907	0.4267	0.25921	IRS	13.30.31	0
25	Sinhua fire branch	1	1	1	1	CRS	25	18
26	Shansun fire branch	0.3002	0.7457	0.4026	0.196375	IRS	1.13.25.3	0
27	Zuojhen fire branch	0.3194	1	0.3194	0.242798	IRS	13.17.31	0
28	Sinshih fire branch	0.5631	0.6816	0.8261	0.487112	IRS	1.25	0
29	Nanke fire branch	0.2164	0.5196	0.4165	0.145505	IRS	1.30	0
30	Yongkan fire branch	1	1	1	1	CRS	30	19
31	Yanhang fire branch	1	1	1	1	CRS	31	6
32	Fusing fire branch	0.7026	0.7557	0.9297	0.702851	IRS	1.25	0
33	Dawan fire branch	0.9445	0.9850	0.9589	0.726519	IRS	30	0
34	Gueiren fire branch	1	1	1	1	CRS	34	6
35	Rende fire branch	0.9342	0.9611	0.9720	0.775896	IRS	25.30.34	0
36	Wunsian fire branch	0.8862	0.9499	0.9329	0.676747	IRS	25.30.34	0
37	Guanmiao fire branch	0.9698	1	0.9698	1.057971	DRS	25	0

Appendix 5-1

The entire relative efficiencies of each fire branch for the each stages and input manpower by conducting GESA

DMUs	The original manpower in the first	Original efficiency	Allocated unit	The efficiency in the second	Allocated unit	The efficiency in the third stage	Allocated unit	The efficiency in the fourth stage
Sinying fire branch	18	1	1	1	1	1	1	1
Yanshuei fire branch	7	0.9434	0	0.9963	0	1	1	0.9651
Liouying fire branch	7	0.9619	0	0.9818	0	1	1	0.9992
Baihe fire branch	8	0.8363	0	0.8940	0	0.9229	0	0.9778
Guanling fire branch	5	0.3046	0	0.3188	0	0.3316	0	0.3486
Houbi fire branch	7	0.6940	0	0.7116	0	0.7452	0	0.7685
Dongshan fire branch	7	0.6689	0	0.6735	0	0.6828	0	0.6895
Dongyuan fire branch	7	0.6376	0	0.6376	0	0.6376	0	0.6376
Syuejia fire branch	9	0.5763	0	0.6029	0	0.6280	0	0.6516
Jiangjyun fire branch	6	0.8302	0	0.8361	0	0.8468	0	0.8580
Beimen fire branch	6	0.3251	0	0.3482	0	0.3679	0	0.3935
Jialu fire branch	10	0.9724	0	1	1	0.9943	0	1
Sigang fire branch	7	1	1	1	1	1	1	1
Cigu fire branch	8	0.6746	0	0.6746	0	0.6798	0	0.6995
Madou fire branch	15	0.8027	0	0.8027	0	0.8131	0	0.8575
Siaying fire branch	8	0.6509	0	0.6966	0	0.7441	0	0.7801
Lioujia fire branch	9	1	1	1	1	1	1	1
Guantian fire branch	8	0.7499	0	0.7812	0	0.8240	0	0.8558
Shanhua fire branch	11	0.7471	0	0.7792	0	0.8190	0	0.8492
Anding fire branch	9	0.6414	0	0.6503	0	0.6789	0	0.7096
Danei fire branch	7	0.3819	0	0.3876	0	0.3923	0	0.4077
Yujing fire branch	6	0.5818	0	0.6233	0	0.6626	0	0.6883
Nansi fire branch	7	0.4677	0	0.4677	0	0.4677	0	0.4677
Nanhua fire branch	6	0.3801	0	0.4046	0	0.4273	0	0.4486
Sinhua fire branch	11	1	1	1	1	1	1	1
Shansun fire branch	8	0.3002	0	0.3010	0	0.3081	0	0.3148
Zuojhen fire branch	6	0.3194	0	0.3423	0	0.3687	0	0.3914
Sinshih fire branch	18	0.5631	0	0.5631	0	0.5631	0	0.5631
Nanke fire branch	14	0.2164	0	0.2164	0	0.2164	0	0.2164
Yongkan fire branch	13	1	1	1	1	1	1	1
Yanhang fire branch	11	1	1	1	1	1	1	1
Fusing fire branch	24	0.7026	0	0.7026	0	0.7026	0	0.7026
Dawan fire branch	10	0.9445	0	1	1	0.9782	0	1
Gueiren fire branch	12	1	1	1	1	1	1	1
Rende fire branch	10	0.9342	0	0.9951	0	1	1	0.9790
Wunsian fire branch	9	0.8862	0	0.9470	0	0.9848	0	1
Guanmiao fire branch	12	0.9698	0	1	1	1	1	1

Appendix 5-2

The entire relative efficiencies of each fire branch for the each stages and input manpower by conducting GESA

DMUs	*Allocated unit*	*The efficiency in the fifth*	*Allocated unit*	*The efficiency in the sixth*	*The finished addition of input total persons*	*Allocation number of on-duty personnel next*
Sinying fire branch	1	1	1	1	4	22
Yanshuei fire branch	0	1	1	0.9494	1	8
Liouying fire branch	0	1	1	1	1	8
Baihe fire branch	0	1	1	0.9713	0	8
Guanling fire branch	0	0.3633	0	0.3795	0	5
Houbi fire branch	0	0.7985	0	0.8229	0	7
Dongshan fire branch	0	0.6946	0	0.7173	0	7
Dongyuan fire branch	0	0.6376	0	0.6376	0	7
Syuejia fire branch	0	0.6743	0	0.6948	0	9
Jiangjyun fire branch	0	0.8668	0	0.8736	0	6
Beimen fire branch	0	0.4115	0	0.4383	0	6
Jialu fire branch	1	1	1	1	2	12
Sigang fire branch	1	1	1	1	4	11
Cigu fire branch	0	0.7470	0	0.7931	0	8
Madou fire branch	0	0.9091	0	0.9376	0	15
Siaying fire branch	0	0.8372	0	0.8832	0	8
Lioujia fire branch	1	1	1	1	4	13
Guantian fire branch	0	0.9010	0	0.9451	0	8
Shanhua fire branch	0	0.9005	0	0.9124	0	11
Anding fire branch	0	0.7344	0	0.7651	0	9
Danei fire branch	0	0.4213	0	0.4363	0	7
Yujing fire branch	0	0.7419	0	0.7720	0	6
Nansi fire branch	0	0.4728	0	0.4885	0	7
Nanhua fire branch	0	0.4687	0	0.4876	0	6
Sinhua fire branch	1	1	1	1	4	15
Shansun fire branch	0	0.3271	0	0.3357	0	8
Zuojhen fire branch	0	0.4111	0	0.4284	0	6
Sinshih fire branch	0	0.5716	0	0.5874	0	18
Nanke fire branch	0	0.2200	0	0.2275	0	14
Yongkan fire branch	1	1	1	1	4	17
Yanhang fire branch	1	1	1	1	4	15
Fusing fire branch	0	0.7026	0	0.7026	0	24
Dawan fire branch	1	1	1	0.9786	2	12
Gueiren fire branch	1	1	1	1	4	16
Rende fire branch	0	1	1	0.9882	1	11
Wunsian fire branch	1	0.9916	0	1	1	10
Guanmiao fire branch	1	1	1	1	3	15